Defense Technical Information Center Compilation Part Notice

ADP010723

TITLE: Selected Data Set from Static and Rolling Experiments on a 65 Deg. Delta Wing at High Incidence

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:

TITLE: Verification and Validation Data for Computational Unsteady Aerodynamics [Donnees de verification et de valadation pour l'aerodynamique instationnaire numerique]

To order the complete compilation report, use: ADA390566

The following component part numbers comprise the compilation report:

ADP010704 thru ADP010735

16E. SELECTED DATA SET FROM STATIC AND ROLLING EXPERIMENTS ON A 65° DELTA WING AT HIGH INCIDENCE

X.Z. Huang, T.C. Lui and E.S. Hanff
IAR/NRC, Canada

INTRODUCTION

This data set is selected from an extensive set of experimental results obtained for configurations with a 65° delta wing under static as well as large-amplitude high-rate rolling or pitching conditions at high incidence. The experiments were performed under a joint research program on "Non-Linear Aerodynamics under Dynamic Maneuvers" by the National Research Council of Canada (NRC (IAR)), the U.S. Air Force (USAF (AFOSR, AFRL)) and the Canadian Dept. for National Defence (DND). NASA Ames informally participated in the program through its substantial CFD work on specific test conditions. The experimental results provide both detail pressure measurements and a wide range of flow conditions covering from simple attached flow, through fully developed vortex and vortex burst flow, up to fully-stalled flow at very high incidence. Since this data set includes different levels of physical difficulty, the computational researchers working in unsteady aerodynamics can use it as a staircase approach to the problem of validating their corresponding code. Four schematic and representative configurations[1] were selected in the experiments (Fig. 1 to Fig. 3):

1) 65° delta wing;
2) 80/65° double delta wing;
3) 65° delta wing with a single vertical tail and a circular ogive forebody,
4) 65° delta wing with a single vertical tail and an elliptical cross section forebody whose major axis could be installed either horizontally or vertically.

Experiments with the above models include the following test parameters:

1) motion variables (rolling or pitching),
2) modes (static or dynamic),
3) motion waveform (harmonic, ramp-and-hold, free-to-roll and "forced" free-to-roll),
4) observed variables (flow visualization, motion history, steady and unsteady loads and surface pressure),
5) wind tunnel interference assessment (by repeat tests in different wind tunnels),
6) support interference assessment (by repeat tests with different supports).

The words of "forced" free-to-roll refer to the experiments performed in the forced mode with the same motion as observed under free-to-roll condition so that the unsteady surface pressures prevailing during free-to-roll motions could be obtained.

Fig. 4 to Fig. 7 show the installation and support arrangements in the two wind tunnels. The models, rolling rig and pitching rig were designed by IAR. Experiments were conducted both at the IAR and AFRL wind tunnels (LSWT and SARL respectively) and Table 1 summarizes the test matrix. A complete list of tests with corresponding conditions can be found in Ref.1-4. The comparisons of repeat tests conducted in different wind tunnels and supports shown in Ref. 1 confirm that both wind-tunnel as well as support interference are negligible.

Due to large number of tests conducted, this data set contains only ten typical cases for the 65° delta wing, listed in Table 2. These cases were selected to cover typical sets of tests such as static tests and harmonic, ramp-and-hold, free-to-roll and "forced" free-to-roll dynamic tests. Seven spanwise-distributed surface pressure transducers on the up surface of the port wing were used to measure the instantaneous surface pressure during the motion. Three typical sting angles: σ=15°, 30° and 35° were selected as being representative of different leading-edge vortex behavior. In the absence of sideslip, at σ=15° the leading-edge vortex is intact over the full length of the model, leading to small non-linearities and time dependence; at σ=30° vortex breakdown occurs over the aft part of the wing leading to severe non-linearities and time dependence; and finally, at σ=35° vortex breakdown is present over the forward portion of the wing resulting in different characteristics.

LIST OF SYMBOLS AND DEFINITIONS

B	wing span, (in)
c	chord, (in)
c_0	mean aerodynamic chord, (in)

C_p	pressure coefficient $=(p-p_0)/qs$
C_{pi}	pressure coefficient measured from transducer at "i" station
C_ℓ	rolling moment coefficient $=\ell/qsB$
C_m	pitching moment coefficient $=m/qsc_0$
C_N	normal force coefficient $=N/qs$
C_p	pressure coefficient $=(p-p_0)/qs$
C_{pi}	pressure coefficient measured from transducer at "i" station
f	frequency, (Hz)
k	reduced frequency $=\pi fB/V_0$
ℓ	rolling moment, (lbs-in)
M	Mach number
m	pitching moment related to 35% MAC, (lbs-in)
N	normal force, (lbs)
n	yawing moment related to 35% MAC, (lbs-in)
p	pressure, (psi)
p_0	free stream static pressure, (psi)
p_{atm}	atmospheric pressure (psi)
q	dynamic pressure, (psi)
s	wing area, (in^2)
S	local semi-span, (in)
T_0	static temperature, (°C)
t	time, (sec)
V_0	free stream velocity, (ft/sec)
x,y,z	body axes coordinates
x_{Cp}	center of pressure in x axis, (in)
y_{Cp}	center of pressure in y axis, (in)
Y	side force, (lbs)
α	angle of attack, (°)
σ	sting angle (between body axis and tunnel axis), (°)
$\phi°$	roll angle, (°)
ϕ_0	mean roll angle or initial roll angle, (°)
ϕ_1	roll angle at end of ramp-and-hold motion, (°)
ϕ_t	roll angle in free-to-roll motion at wind-off condition, (°)
ϕ_w	roll angle in free-to-roll motion at wind-on condition, (°)
$\Delta\phi$	amplitude, (°)
$\dot{\phi}$	roll angular rate, (rad/sec)
$\dot{\Phi}$	non-dimensional rolling frequency $= \dot{\phi}B/2V_0$

FORMULARY

1 General Description of model

1.1	Designation	IAR/AFRL 65° delta wing
1.2	Type	Full model
1.3	References	Ref. 1 (Fig. 1 to Fig. 3)

2 Model Geometry

2.1	Planform	Delta wing
2.2	Aspect ratio	1.866
2.3	Leading edge sweep	65°
2.4	Trailing edge sweep	0°
2.5	Span	22.835 in
2.6	Root chord	24.485 in
2.7	Area of planform	279.486 in^2
2.8	Twist	0°
2.9	Leading-edge bevel (leeward)	10° (perpendicular to leading-edge)
2.10	Leading-edge bevel (windward)	10° (perpendicular to leading-edge)
2.11	Trailing edge bevel (leeward)	10° (perpendicular to trailing edge)
2.12	Trailing edge bevel (windward)	10° (perpendicular to trailing edge)
2.13	Area of planform	279.486 in^2
2.14	Leading-edge radius	0.020 in
2.15	Tolerance of leading-edge radius	±10%
2.16	Mean aerodynamic chord	16.323 in
2.17	Thickness of flat area	0.375 in
2.18	Reference center	13.875 aft of the apex
2.19	Center-body diameter	3.150 in
2.20	Radius of forebody	$r = \sqrt{24.103^2 - (12.243 - x)^2} - 22.528$ in

3 Wind Tunnel

3.1	Designation	LSWT (IAR)
3.1.1	Type of tunnel	Close-circuit atmospheric type
3.1.2	Test section dimensions	Height: 6 ft, width: 9ft, length: 15 ft
3.1.3	Type of roof and floor	Solid with large optical quality plexiglass windows
3.1.4	Maximum speed	390 ft/sec
3.1.5	Contraction ratio	9
3.1.6	Turbulence in empty tunnel	≤ 0.12% at free stream speed of 100 ft/sec
3.1.7	Support	Sting attached to wind tunnel strut (Fig. 4)
3.1.8	Type of side walls	Solid with large optical quality plexiglass windows
3.1.9	Type of roof	Solid with large optical quality plexiglass windows
3.1.10	Tunnel resonance	No evidence of resonance in present test
3.1.11	Reference	Ref. 5
3.2	Designation	SARL wind tunnel (AFRL)
3.2.1	Type of tunnel	Open-circuit atmospheric type
3.2.2	Test section dimensions	Height: 10 ft, width: 7ft, length: 15 ft
3.2.3	Maximum speed	660 ft/sec
3.2.4	Contraction ratio	36
3.2.5	Turbulence in empty tunnel	≤ 0.1%
3.2.6	Type of side walls	Solid with large optical quality plexiglass windows

3.2.7	Type of roof	Solid with large optical quality plexiglass windows
3.2.8	Support	Roll rig is shown in Fig. 4 and Fig. 5 while pitch rig is shown in Fig. 6 and Fig. 7
3.2.9	Tunnel resonance	No evidence of resonance in present test
3.2.10	Reference	Ref. 6

4 Model motion

4.1	General description	Rolling about body axis with following motions: Sinusoidal (§4.6) Ramp-and-hold (§4.7) Free-to-roll and "forced" free-to-roll (§4.8)
4.2	Method of applying motion	Inexorable hydraulic system (3,000 psi, 50 hp)
4.3	Model deformation	Negligible
4.4	Roll angle precision	0.175°
4.5	Sting angle precision	0.1°
4.6	Sinusoidal motion	
4.6.1	Maximum oscillation amplitude	40°
4.6.2	Maximum mean roll angle	± 50°
4.6.3	Maximum frequency	18 Hz
4.7	Ramp-and hold motion	
4.7.1	Waveform	Constant velocity with constant acceleration at both ends, or Only constant acceleration at both ends (double parabola)
4.7.2	Maximum of angular rate	4500 °/sec
4.7.3	Maximum of angular acceleration	500,000 °/sec^2
4.8	Free-to-roll and "forced" free-to-roll	
4.8.1	Maximum initial roll angle	90°
4.8.2	Tare friction	Approximately constant (independent of rate)

5 Test Conditions

5.1	Model planform area/tunnel area	0.0296 (SARL) and 0.0357 (LSWT)
5.2	Model span/tunnel height	0.300 (LSWT)
5.3	Model span/tunnel width	0.272 (SARL)
5.4	Model center chord/ tunnel height	0.204 (SARL)
5.5	Model center chord/ tunnel width	0.227 (LSWT)
5.6	Blockage at α=30°	0.0148 (SARL) and 0.0179 (LSWT)
5.7	Position of model in tunnel	Standard side position (LSWT) Standard upright position (SARL)
5.8	Rolling moment of inertia	0.15 lbs-in-sec^2
5.9	Range of tunnel total pressure	Atmospheric (SARL) Atmospheric static pressure (LSWT)
5.10	Definition of model sting angle	Angle between body axis and tunnel axis
5.11	Sting deformation under static loads	Negligible in (LSWT) and 1°at σ=30° in (SARL)

6 Measurements and Observations

6.1	Steady pressure for static conditions	Yes
6.2	Unsteady pressures for dynamic conditions	Yes
6.3	Steady forces for static conditions	Measured directly
6.4	Unsteady forces for dynamic conditions	Measured directly
6.5	Measurement of actual motion of model	Yes
6.6	Measurement of free-to-roll motion history	Yes
6.7	Observation or measurement of boundary layer properties	Yes
6.8	Visualisation of surface flow	Yes
6.9	Visualization of off-surface flow	Yes
6.10	Wind tunnel interference assessment	Yes
6.11	Support interference assessment	Yes

7 Instrumentation

7.1 Steady pressure

7.1.1	Position of orifices spanwise and chordwise	see Fig. 1
7.1.2	Type of measuring system Operation mode Sensitivity range Zero pressure output:	Kulite pressure transducers (LQ-47-25A) with "B" screen Absolute 3.21~4.46 mv/psi $<\pm 5\%$ full scale
7.1.3	Installation of transducers	Using RTV adhesive flush ($^{0.000}_{-0.005}$) to upper surface. Fill trough with clear epoxy filler fair to upper surface.
7.1.4	Principle and accuracy of calibration	Kulite: static calibration at beginning of tunnel entry, offset measurement every 30 minutes.

7.2 Unsteady pressure

7.2.1	Position of orifices	See Fig. 1
7.2.2	Type of transducers	Same as §7.1.1
7.2.3	Method and accuracy of calibration	Kulite: static calibration at beginning of tunnel entry, offset measurement every 30 minutes

7.3 Steady loads

7.3.1	Type of transducers	Strain gauge
7.3.2	Type of measuring system	Five components balance with maximum range: Normal force N=2,000 lbs Side force Y=1,000 lbs Rolling moment ℓ=3,000 lb-in
7.3.3	Method and accuracy of calibration	Maximum and relative deviations: Normal force $\Delta N_{max} = \pm 2$ lbs, $\delta N_{max}=0.1\%$ Pitch moment $\Delta m_{max}=\pm 5$ lbs-in ($\Delta x_{max}= 0.005$ in) Side force $\Delta Y_{max} = \pm 2$ lbs, $\delta Y_{max}=0.1\%$ Yawing moment $\Delta n_{max}=\pm 5$ lbs-in ($\Delta y_{max}= 0.005$ in) Rolling moment $\Delta \ell_{max}=\pm 6$ lbs-in $\delta C\ell_{max}=0.2\%$

7.4 Unsteady loads

7.4.1	Type of transducers	Strain gauge
7.4.2	Measurement method	Ensemble average of coherent samples taken over several cycles
7.4.3	Method and accuracy of calibration	
7.5	Model motion	
7.5.1	Method of measurement	Angular encoder on driveshaft aft end
7.5.2	Accuracy	±0.1°
7.5.3	Sting acceleration (horiz. and vert.)	Accelerometer EGA-125*-10D Non-linearity: ±1% Range: ±10 g Limit: ±50 g Them.Z ±1%FS/100°F TSS ±2.5% /100°F
7.6	Processing of unsteady measurements	
7.6.1	Pressure signal acquisition	See Fig. 8a (up to 1991)
7.6.2	Loads signal acquisition	See Fig. 8b (up to 1991)
7.6.3	Processing data	Ensemble average over more than 30 (harmonic motion), or 9 cycles (ramp-and-hold motion)

8 Data presentation

8.1	Test cases for which data could be made available	Table 1
8.2	Test cases for which data are included in this document	Table 2
8.3	Data presentation	See CD-ROM (in Tecplot format)
8.4	Electronic data file index	Table 3
8.5	Examples of lay-out of data files	Table 4 at page 23
8.6	Some illustration of results	See page 17 to 22

9 Personal contact for further information

Xing Zhong Huang and Ernest S. Hanff, Aerodynamics Laboratory, Institute for Aerospace Research, National Research Council of Canada, Montreal Rd. Ottawa, Canada, K1A 0R6.
e-mail address: xingzhong.huang@nrc.ca and ernest.hanff@nrc.ca

10 List of references

[1]. Hanff, E.S. and Huang, X.Z., "Rolling and Pitching Experiments on Configurations with a 65° Delta Wing at High Incidence" NRC/IAR LTR-A-013, 1997.

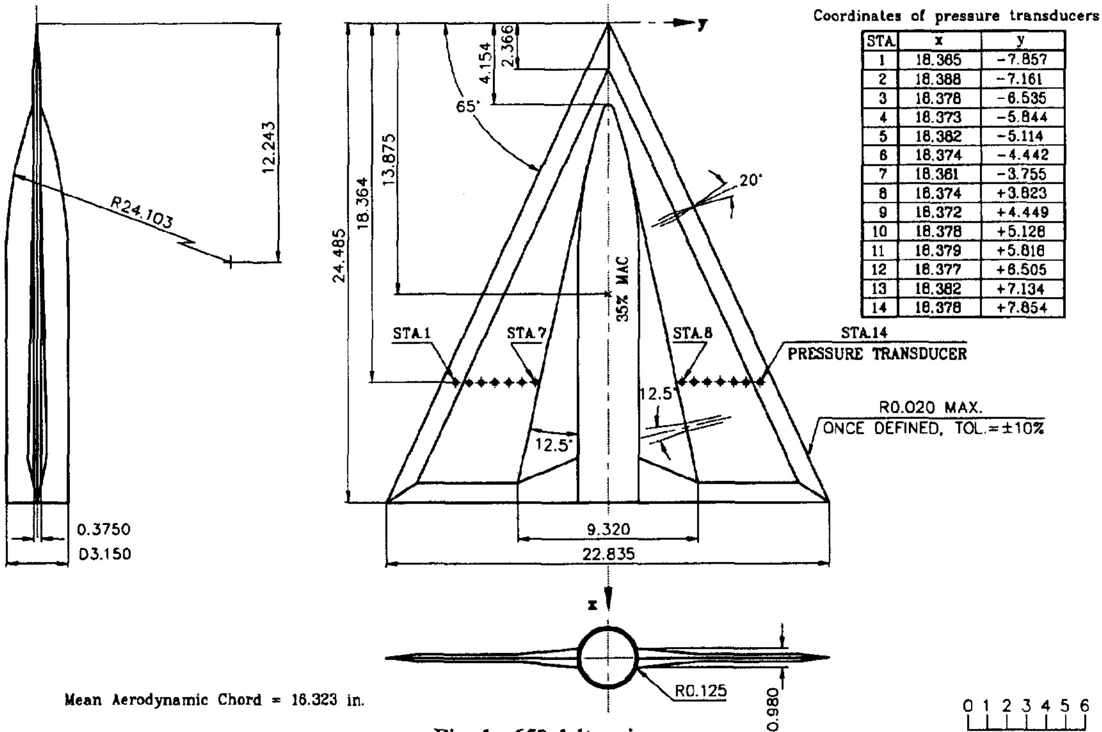
[2]. Jenkins, J.E. and Hanff, E.S., "Highlights of the IAR/WL Delta Wing Program" AIAA Atmospheric Flight Mechanics Conference, Workshop III, August 1995

[3]. Hanff, E.S. and Jenkins, S.B., "Large-Amplitude High-Rate Roll Experiments on a Delta and Double Delta Wing," AIAA Paper 90-0224, 1990.

[4]. Hanff, E.S., Kapoor, K, Anstey, C.R. and Prini, A., "Large-Amplitude High-Rate Roll Oscillation System for the Measurement of Non-Linear Airloads," AIAA Paper 90-1426, 1990.

[5]. Brown, T.R., "Description of the 6-ft x 9-ft Low Speed Wind Tunnel," NRC, NAE LTR-LA-285, Nov. 1986.

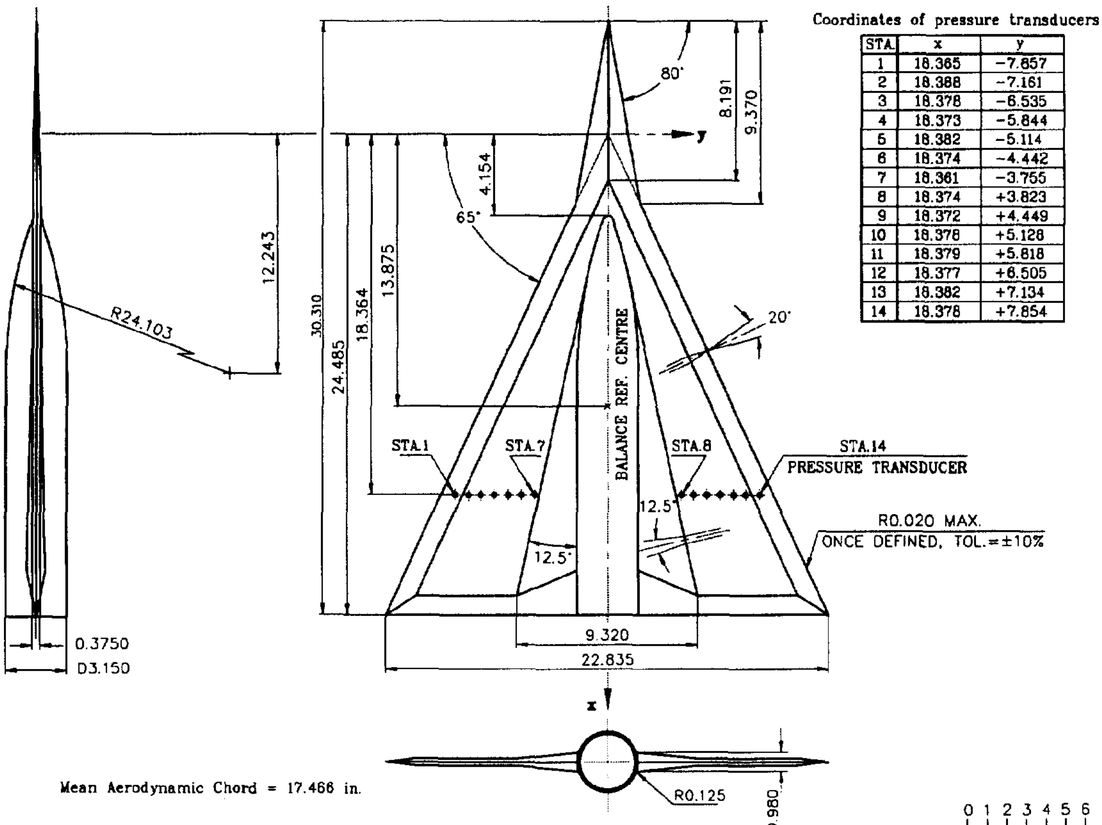
[6]. Presdorf, T.A., "Subsonic Aerodynamic Research Laboratory," USAF WL-TR-92-3053, Aug., 1992.



Coordinates of pressure transducers

STA	x	y
1	18.365	-7.857
2	18.388	-7.161
3	18.378	-6.535
4	18.373	-5.844
5	18.382	-5.114
6	18.374	-4.442
7	18.361	-3.755
8	18.374	+3.823
9	18.372	+4.449
10	18.378	+5.128
11	18.379	+5.818
12	18.377	+6.505
13	18.382	+7.134
14	18.378	+7.854

Fig. 1 65° delta wing



Coordinates of pressure transducers

STA	x	y
1	18.365	-7.857
2	18.388	-7.161
3	18.378	-6.535
4	18.373	-5.844
5	18.382	-5.114
6	18.374	-4.442
7	18.361	-3.755
8	18.374	+3.823
9	18.372	+4.449
10	18.378	+5.128
11	18.379	+5.818
12	18.377	+6.505
13	18.382	+7.134
14	18.378	+7.854

Fig. 2 80°/65° double delta wing

Coordinates of pressure transducers

STA.	x	y
1	6.121	+7.850
2	6.121	+7.170
3	6.121	+6.490
4	6.121	+5.810
5	6.121	+5.130
6	6.121	+4.450
7	6.121	+3.770
8	1.347	+9.891
9	1.347	+7.321
10	1.347	+4.750
11	6.121	−5.810
12	12.242	+5.233
13	12.242	+3.873
14	12.242	+2.513

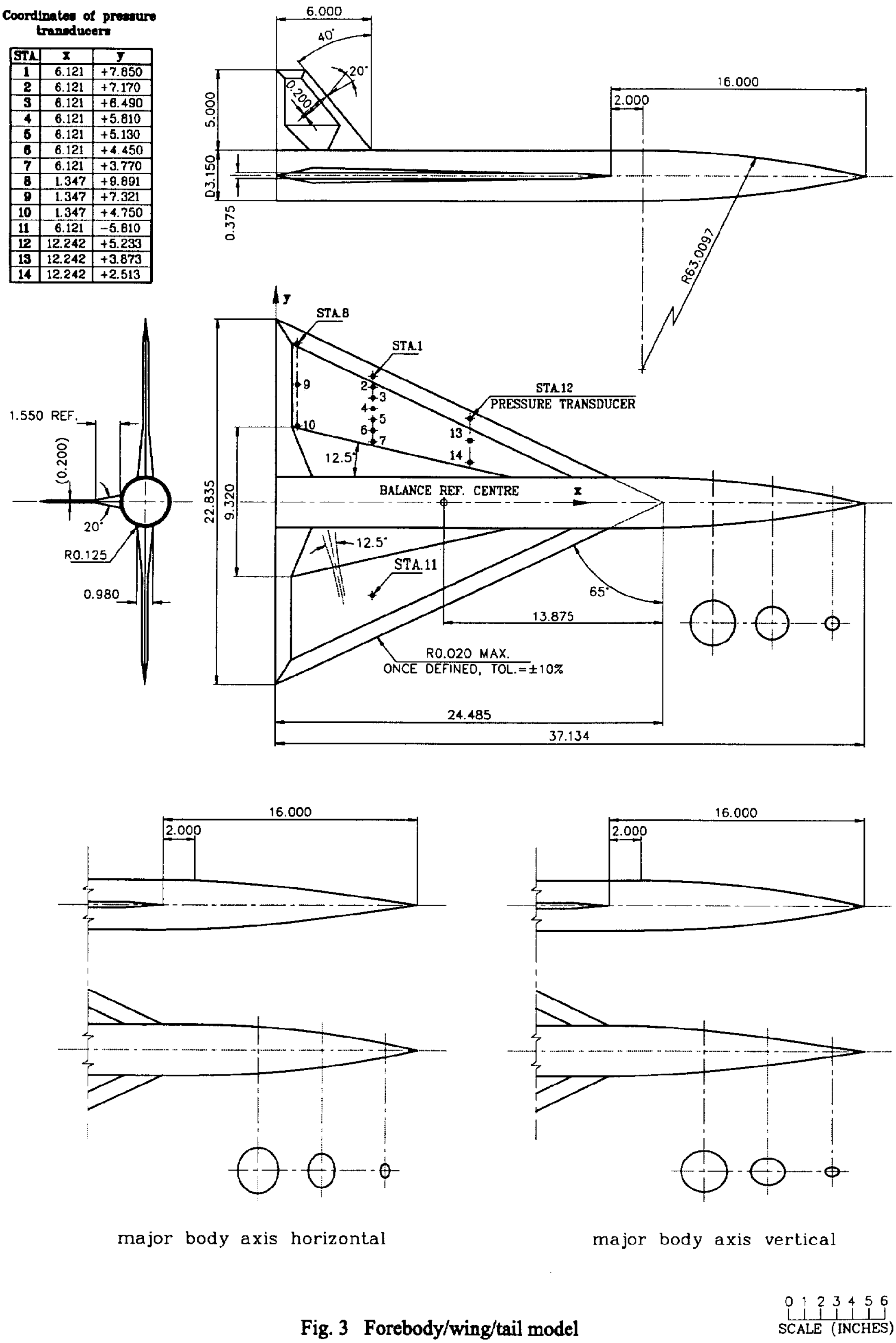


Fig. 3 Forebody/wing/tail model

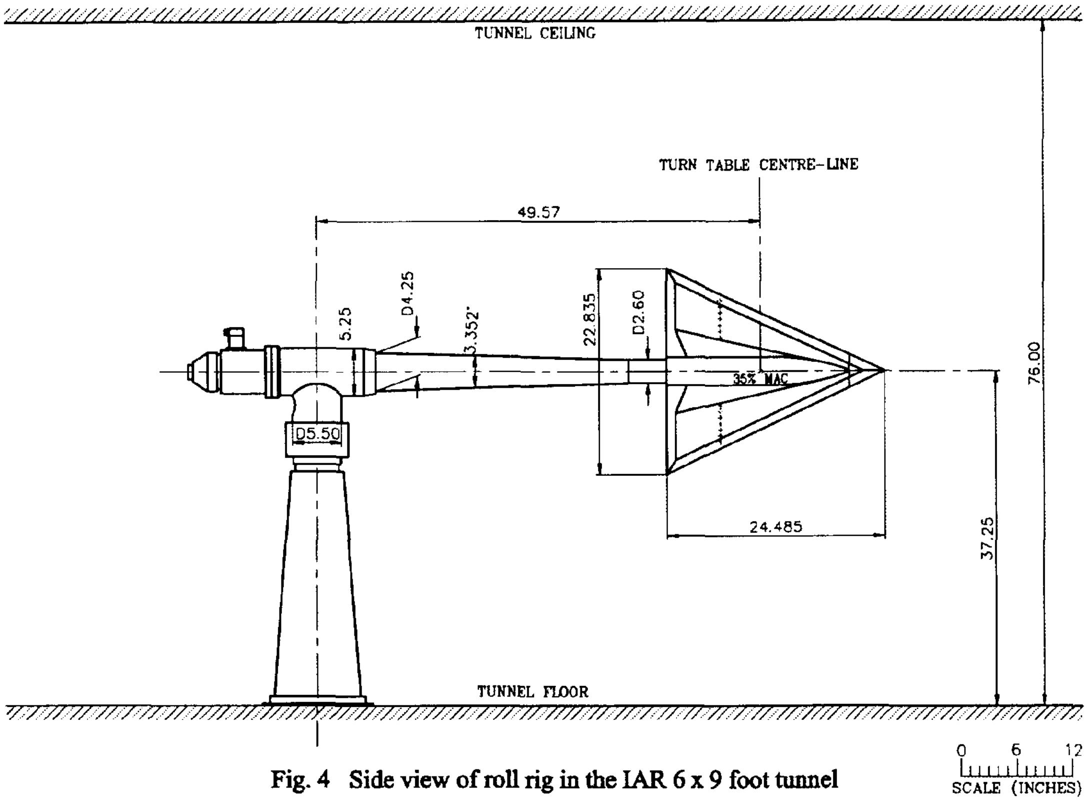


Fig. 4 Side view of roll rig in the IAR 6 x 9 foot tunnel

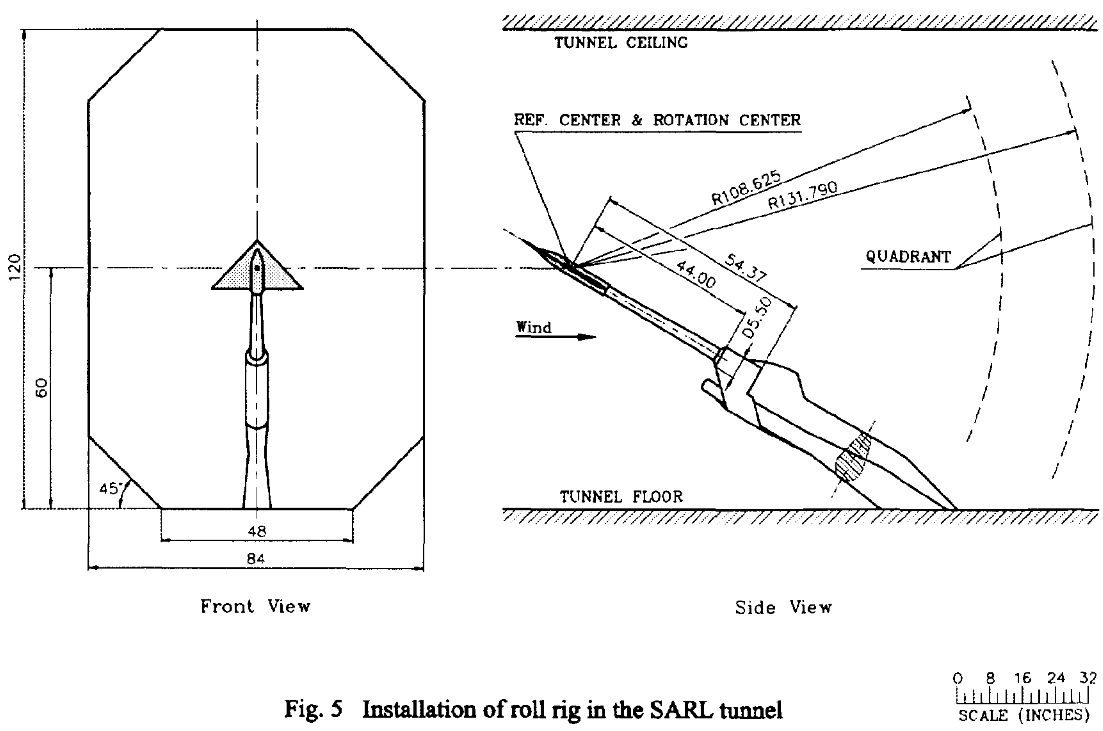


Fig. 5 Installation of roll rig in the SARL tunnel

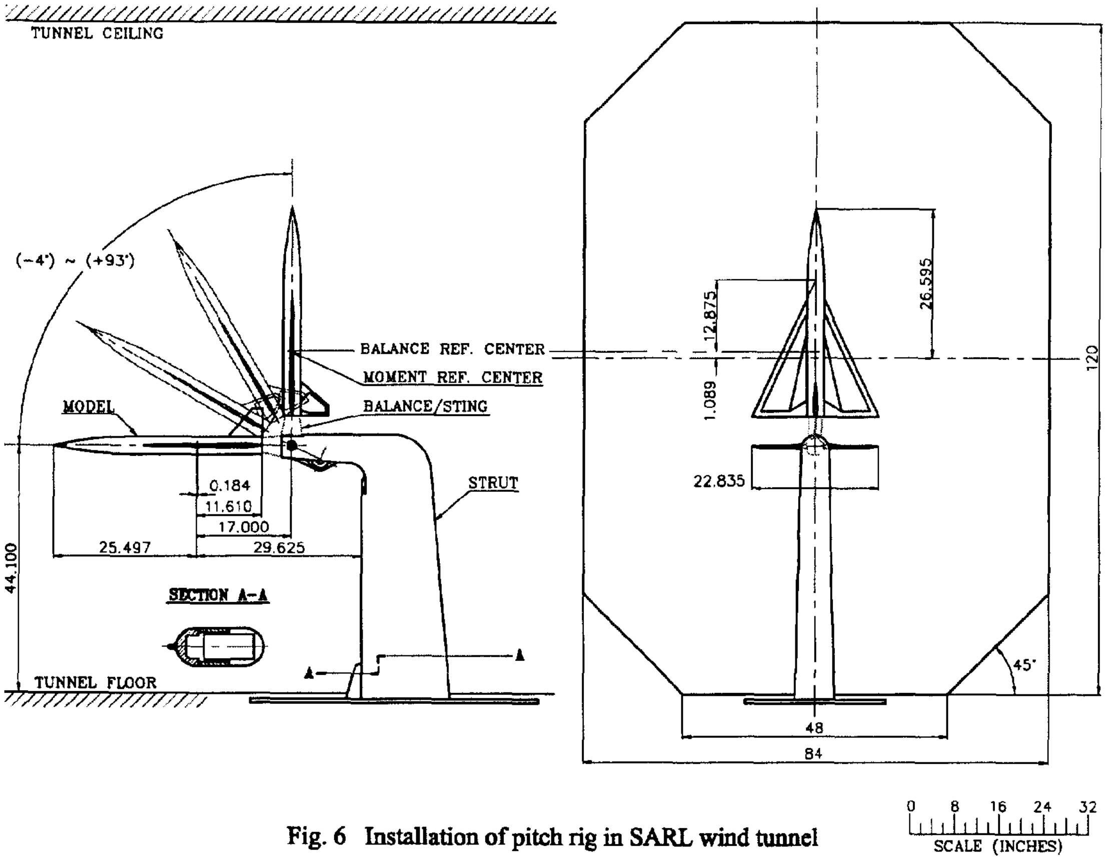


Fig. 6 Installation of pitch rig in SARL wind tunnel

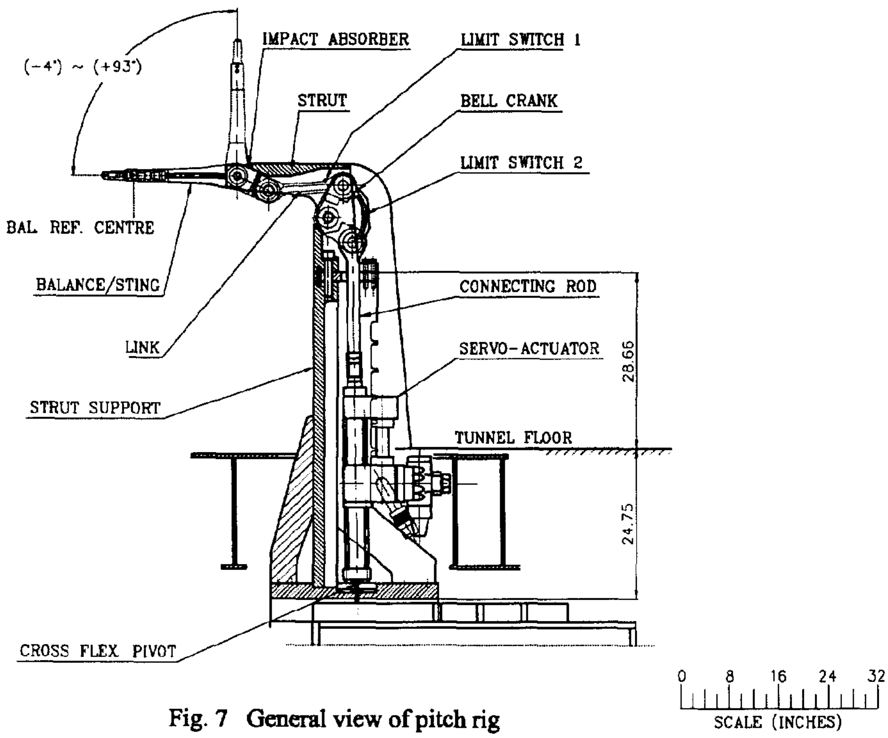


Fig. 7 General view of pitch rig

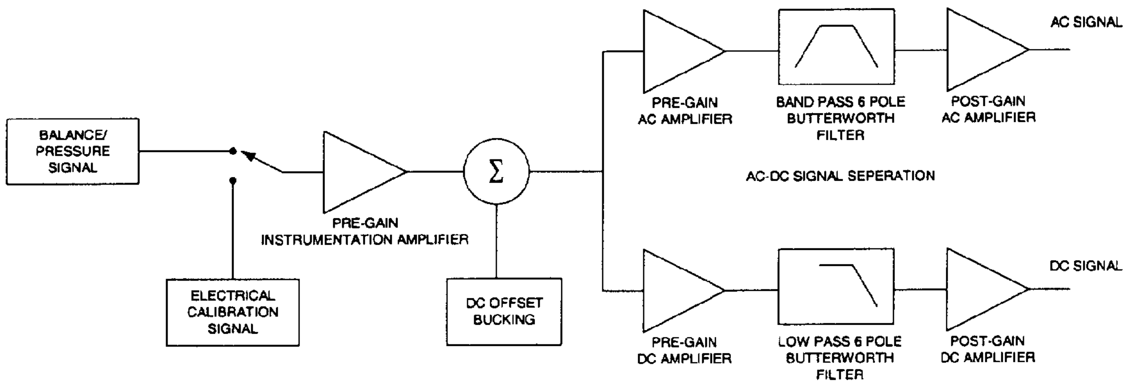


Fig. 8a Signal conditioning for data acquisition used up to 1991

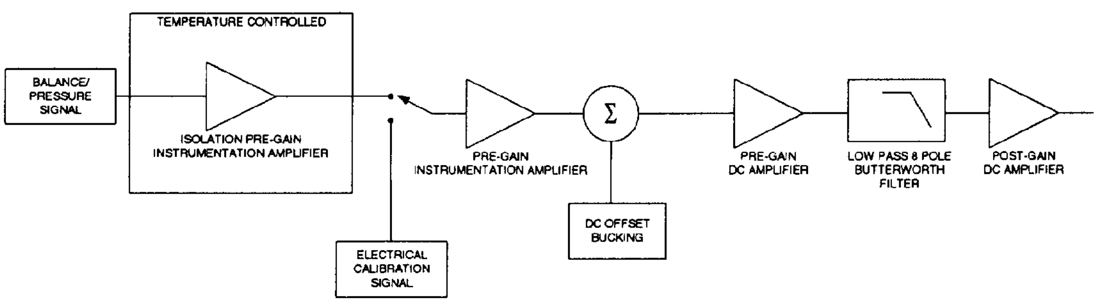


Fig. 8b Signal conditioning for data acquisition used after 1991

Table 1 Roll and pitch test conditions (1989~1994)

Mode	Tests	Motion	Model	V_0(ft/s)	σ(°)	Δφ(°)	ϕ_0(°)	f(Hz), or roll rate and Δt in ramp motion	
Roll	Flow Vis.	Static	65,80/65	160,300,580,	15,17.5, 20,22.5, 25,30, 35,40,		-42,-35,-28,-21,-14,-7,-1,0,1,1.2,2.5,2.6, 3,4,6,4.8,5,5.2,5.4,6,6.5,7,7.5,8.4,9, 11,11.2,13,17,19,21,27,35,37,47,49, 51,55,57,58,59,60,61,62,67, 2~52,Δφ=2;		
		Dynamic	65,80/65	39.5,69,79,92, 121,138,158, 160,277,300, 345,395,580,	30,40	5,12,19,26,33,40	0,14,28,42	f(Hz)	1,1.1,2.2,4,4.4,7,7.7,
	Loads/pressure	Static	65,80/65 W+B(c)	300,330,580,	15,17.5,20, 25,30,33, 34,35,40, 44.5,-35		-90~90, Δφ=2.0; -23.8~23.8,Δφ=0.2; -10~27.5,Δφ=0.5; 49.5~54.5,Δφ=0.25; 61.5~64.5,Δφ=0.25; -85,-55,-49,-47,-45,-35,-25,-15,-11,-6.3, 0.9,1.1,1.9,2.1,2.9,3,3.1,3.7,3.9,4.1,4.9,5,5.1,5.9, 6.1,6.25,6.3,6.75,6.9,7.1,7.25,7.3,7.75,7.9,9,9.1, 9.9,10.9,11.1,11.9,13.9,14.1,14.5,27.8,27.9, 28.1,28.2,28.6,28.8,33,35,39,41.5,41.6,41.8, 41.9,42.1,42.9,43,45,47,48.5,55,55.5,56.1,56.3, 57,57.3,57.6,61,65,69.9,70.1,71.5,71.6,		
		Harmonic	65,80/65, W+B (c)	123,162, 280,300,330, 540,550, 580,	15,30,35,	2,3,4,5,6,8,10,12,15, 16,17,18,19,22,23,24, 26,27,30,31,32,33,34, 36,38,39,40,	-55,-35,-30,-28,-20,-10,-6,-2,0,1,2,2.5,3,4,5,6, 6.5,7,8,9.5,9.7,10,11,12,13,14, 15,18,18.5,20,21,21.5,25,27,28,30, 37.5,40,41,42,50,54,55,60,62,	f(Hz)	1.1,2.2,3.3,4,4.4,5.5,7,7.7,8.8,10,11,
		Ramp/vis.	65, W+B(c)	330	15,30,35	-30~-28,-26,-25,-24,-22,-20,-18,-16,-15, -30~-14,-12,-10,-5,0,5,10, -25~-20,-18,-16,-14,-12,-10,-8,-6,-4,25, -16~16, -12~12, -10~26,-24,-22,-20,-18,-17,-16,-15,-14,-12,12 -7~3, -4~4,6,7,9,10, -2~22, -1~0,2,3,5,7, 0~-7,9, 2~3,5,7,18, 3~-1,0,2, 5~8,10,17, 6~7,9,10,12,20, 7~-4,-1,0,2,3,4,5,6, 8~9,10,11,12,13,14,15,16,17,18,19,20, 9~10,12,20,26,29,35,60,80, 10~-30,-25,-20,-15,-10,-6,-5,-4,-2,0,4,5,6,7,9, 10~10,18,19,20,21,22,40, 12~9,24,26,29,35, 17~5,8,10, 19~21,22,40, 20~-20,6,7,9,10,12,18,19,32, 25~10,11,12,13,14,15,16,17,18,19,20,21,22,23, 30~-15,-10,-5,0,5,10,15,20,25, 35~9,10,12,26,29, 40~-40,9,10,18,19,21,22,40,53,56,61,63,64,70, 45~60, 56~68, 64~53,56,		roll rate (rad/ms)	0.5,1,4,7, 1.1,3.56,3.59,6.08,7.93,8.58,11.1,12.3, 13.6,16.1,16.7,17.3,18.5,21,23.5,25.4, 26,28.5,29.7,31,33.5,34.1,34.7,34.8,
								Δt(ms)	36,38.5,41,42.8,43.5,46,47.2,48.5,51, 51.6,52.2,53.5,55.9,58.4,60.3,60.7, 60.9,63.4,64.6,69,69.6,69.7,73.4,75.9, 77.7,78.4,82.1, 86.5,86.9,87.1,90.8, 95.2, 98,99.6,100,104,105,108,113,122, 123,126,130,134.5,139,140,157,174,176, 192,209,217,221.7,227,244,262,279, 296,309,314,331,348,349,366,,384, 401,419,436,454,489,523,541,558, 628,698,744,838,872,1082,1117,1239, 1396,1745,1780,2234,2478,2792,
	Free-to-roll			330,580	30,35		-2,-2.9,-3,-3.4,-3.5,-3.8,-6.8,-8.6,-9.8,-21, -23.1,-27,-27.7,-32.7,-35.6,-36.1, -37.8,-38.4, -43.8,-44.6,-45.7,-53.9,-54.1,-54.2, -55.6,-59.5,-59.8,-62.1,-62.7, -65.9,-68.6,-69.1,-69.3,-71.5,-80.8 0,4.9,5.2,5.6,6.9,9,18.9,18.6,20.9,22.5, 23.8,29.3,30.5,35.3,39.8,44.5,47.7,48.1, 50.6,50.8,53.7,55.2,56.2,58.1,59.1,59.2, 60.5,60.6,61.1,61.2,61.8,62.6,62.7,62.8, 63.6,64.2,64.5,64.8,64.9,65.3,65.7, 66.9,67.5,68.1,70.2,		

Table 1 Roll and pitch test conditions
(1989~1994)

Mode	Motion	Tests	Model	V_0(ft/s)	f(°)	Δα(°)	α_0(°)	Δt(ms)
Pitch	Flow vis.	static	65	330	0		0,1,2,5,10,12,14,15,17,20,22,24,24.6,24.8,25,25.2,25.4,25.5,25.6,25.8,26,26.2,27,28,29,30,31,32.5,35,37,38,39,40,44,45,45.5,	
		Dynamic	65	330	0	10,20,30,40,50,60,70,80,90,	0,1,2,	47.4,50,72.3,75,97.2,100,105,122,147,150,172,194,199,200,209,225,250,314,419,524,628,675,733,838,942,1047,1257,1466,1885,
						-10,10,20,30,40,50,60,70,79,	10,	50,75,100,105,150,175,199,209,225,249,250,299,314,349,399,419,524,628,675,733,838,
						-20,-18,-10,10,20,30,40,50,60,70,	20,	50,75,100,105,150,199,209,225,249,250,299,314,349,419,524,628,675,733,
						-28,-20,-10,10,20,30,40,50,60,	30,	25,50,75,100,105,150,199,209,225,249,250,299,314,349,419,524,628,675,
						-38,-30,-20,-10,10,20,30,40,50,	40,	25,50,75,100,105,120,150,199,209,225,249,250,299,314,349,419,524,628,675,
						-48,-40,-30,-20,-10,10,20,30,38,	50,	50,75,100,105,150,199,209,225,244,249,250,314,419,524,675,
						-59,-50,-40,-30,-20,-10,10,20,29,166+167	60,	50,75,100,105,125,150,209,225,250,314,419,524,628,675,
						-69,-60,-50,-40,-30,-20,-10,10,20,	70,	50,75,100,105,209,225,250,314,349,419,524,628,675,733,
						-80,-70,-60,-50,-40,-30,-20,-10,10,	80,	50,75,100,105,150,175,194,199,209,225,250,314,349,399,419,524,628,675,733,838,
						-59,-49,	88,89,	75,225,244,294,344,524,628,675,
						-90-80-70-60-40-30-20-10	90,	105,209,225,250,314,419,628,675,733,838,942,
	Loads/pressure	Static	65	330,580,	0		0~90, Δα=1; 25.5,32.5; 34.5~48.5,Δα=1 24.6,24.8,25.2,25.4,25.6,25.8,26.2,38.8,39.2,39.4,39.6,39.8,40.5,44.5,45.8,46.2,46.4,46.6	
		Harmonic	65	330	0	10,20,22,24,26,30,40,43,44,45,46,47,48,50,60,70,80,90(88)	0,	49.9,75,99.7,104.7,149.6,199.5,209.4,225,249.3,314.2,418.9,523.6,628.3,675,733,837.8,942.5,
						39,49,59,	1,	47.4,72.3,97.2,122.2,147.1,172,194.5,225,244.3,294.2,344.1,
						68,78,88,	2,	75,194.5,225,339.1,389,428.9,438.8,675,
						-10,10,12,14,16,20,30,40,50,60,70,80,	10,	49.9,75,99.7,104.7,149.6,174.5,199.5,209.4,225,249.3,299.2,314.2,349.1,398.9,418.9,523.6,628.3,675,733,837.8,
						-20,-10,10,20,23,24,25,26,27,30,40,50,60,70,	20,	49.9,75,99.7,104.7,149.6,199.5,209.4,225,249.3,299.2,314.2,418.9,523.6,628.3,675,733,
						-30,-28,-20,-10,10,20,30,40,50,60,	30,	24.9,49.9,75,94.7,99.7,104.7,209.4,314.2,418.9,523.6,
						-7.8,-9.8,-11.8,	35,	225,675,
						-40,-38,-30,-20,-10,10,20,30,40,50,	40,	24.9,49.9,74.8,75,99.7,104.7,119.7,149.6,194.5,209.4,314.2,418.9,523.6,
						-17.8,-19.8,-21.8,	45,	225,675,
						-48,-40,-30,-20,-10,10,20,30,38,40,	50,	24.9,49.9,75,99.7,104.7,149.6,199.5,209.4,225,244.3,314.2,418.9,523.6,
						-59,-50,-40,-30,-20,-10,10,20,29,30	60,	49.9,75,99.7,104.7,124.7,149.6,209.4,225,249.3,299.2,314.2,418.9,523.6,628.3,675,
						-15.9,-17.9,-19.9,	65,	225,675,
						-70,-69,-60,-50,-40,-30,-20,-10,10,20,	70,	74.8,75,99.7,104.7,149.6,199.5,209.6,225,249.3,314.2,349.1,418.9,523.6,628.3,733,675,
						-80,-70,-60,-50,-40,-30,-20,-10,10,	80,	75,99.7,104.7,149.6,174.5,194.5,199.5,209.6,225,314.2,418.9,523.6,628.3,675,733,837.8,895.3,
						-37.9,-39.9,-41.9,	85,	225,675,
						-90,-80,-70,-60,-50,-40,-30,-20,-10,	90(88),	75,104.7,209.6,225,244.3,294.2,314.2,344.1,393.9,418.9,523.6,628.3,675,733,837.8,942.5,
		Ramp	65	330	0	2,	22,24,26,43,45,47,	10.06
						-2,	23.2,25.2,27.2,45.1,47.1,49.1,	10.06

Table 2 Selected test cases

Case	Motion	σ°	Condition				Measurement	Run No.	Year	Tunnel
			ϕ°	$\Delta\phi$	f	M				
1	static	15	-42~42			0.3	loads	L02211~02231	1991	SARL
2	static	15	0~42			0.3	pressure	L11001~11014	1991	SARL
3	harmonic	15	0.1	18.7	7.7	0.3	loads	L02158	1991	SARL
	harmonic	15	0.1	25.4	7.7	0.3	loads	L02157	1991	SARL
	harmonic	15	0.1	32.3	7.7	0.3	loads	L02156	1991	SARL
	harmonic	15	0.2	39.1	7.7	0.3	loads	L02155	1991	SARL
	harmonic	15	13.6	18.7	7.7	0.3	loads	L02178	1991	SARL
	harmonic	15	13.6	25.4	7.7	0.3	loads	L02177	1991	SARL
	harmonic	15	13.5	32.1	7.7	0.3	loads	L02176	1991	SARL
	harmonic	15	13.5	38.9	7.7	0.3	loads	L02175	1991	SARL
	harmonic	15	0.4	39.7	7.7	0.3	pressure	L11273	1991	SARL
	harmonic	15	0.4	32.8	7.7	0.3	pressure	L11274	1991	SARL
	harmonic	15	0.4	25.9	7.7	0.3	pressure	L11275	1991	SARL
	harmonic	15	0.4	19	7.7	0.3	pressure	L11276	1991	SARL
4	ramp	15	0~9			0.3	loads	DW3411	1994	SARL
	ramp	15	12~9			0.3	loads	DW3412	1994	SARL
	ramp	15	20~9			0.3	loads	DW3413	1994	SARL
	ramp	15	40~-40			0.3	loads	DW3414	1994	SARL
	ramp	15	0~9			0.3	loads	DW3415	1994	SARL
	ramp	15	12~9			0.3	loads	DW3416	1994	SARL
	ramp	15	20~9			0.3	loads	DW3417	1994	SARL
	ramp	15	40~-40			0.3	loads	DW3418	1994	SARL
	ramp	15	0~9			0.3	loads	DW3419	1994	SARL
	ramp	15	12~9			0.3	loads	DW3420	1994	SARL
	ramp	15	20~9			0.3	loads	DW3421	1994	SARL
	ramp	15	40~-40			0.3	loads	DW3422	1994	SARL
	ramp	15	0~9			0.3	loads	DW3423	1994	SARL
	ramp	15	12~9			0.3	loads	DW3424	1994	SARL
	ramp	15	20~9			0.3	loads	DW3425	1994	SARL
	ramp	15	40~-40			0.3	loads	DW3426	1994	SARL
5	static	30	-64~64			0.3	loads	SW01000~1141	1994	SARL
6	harmonic	30	0	28.2	10	0.3	loads	L00371	1989	IAR
	harmonic	30	-0.1	18.4	7	0.3	Loads	L00354	1989	IAR
	harmonic	30	0	18.4	7	0.3	pressure	L10290	1990	IAR
	harmonic	30	28	31.9	10	0.3	loads	L00384	1989	IAR
	harmonic	30	14	18.5	7	0.3	loads	L00359	1989	IAR
	harmonic	30	14	18.5	7	0.3	pressure	L10293	1990	IAR
7	ramp	30	-16~16			0.3	loads	DW3000	1994	SARL
	ramp	30	16~-16			0.3	loads	DW3001	1994	SARL
	ramp	30	-16~16			0.3	loads	DW3002	1994	SARL
	ramp	30	16~-16			0.3	loads	DW3003	1994	SARL
	ramp	30	-16~16			0.3	loads	DW3004	1994	SARL
	ramp	30	16~-16			0.3	loads	DW3005	1994	SARL
	ramp	30	-16~16			0.3	loads	DW3006	1994	SARL
	ramp	30	16~-16			0.3	loads	DW3007	1994	SARL
	ramp	30	-4~4			0.3	loads	DW3036	1994	SARL
	ramp	30	-4~6			0.3	loads	DW3037	1994	SARL
	ramp	30	-4~7			0.3	loads	DW3038	1994	SARL
	ramp	30	-4~4			0.3	loads	DW3039	1994	SARL
	ramp	30	-4~6			0.3	loads	DW3040	1994	SARL
	ramp	30	-4~7			0.3	loads	DW3041	1994	SARL
	ramp	30	-4~4			0.3	loads	DW3042	1994	SARL
	ramp	30	-4~6			0.3	loads	DW3043	1994	SARL
	ramp	30	-4~7			0.3	loads	DW3044	1994	SARL
	ramp	30	7~-4			0.3	loads	DW3050	1994	SARL
	ramp	30	7~-4			0.3	loads	DW3053	1994	SARL
	ramp	30	7~-4			0.3	loads	DW3055	1994	SARL
8	static	35	-60~68			0.3	loads	SW1142~1314	1994	SARL
9	harmonic	35	0	5.2	4	0.3	loads	L01360	1989	IAR
	harmonic	35	0	5.2	4	0.3	pressure	L10379	1990	IAR
	harmonic	35	33.6	28	7	0.3	loads	L1111	1989	IAR
	harmonic	35	33.8	27.9	7	0.3	pressure	L10447	1990	IAR
10	forced	30	64.5			0.3	pressure	TW0001	1991	SARL
	free-to-roll	30	53			0.3	pressure	TW0016	1991	SARL
		35	66.7			0.3	pressure	TW0032	1991	SARL
		35	53			0.3	pressure	TW0036	1991	SARL

Table 3 Electronic data file index

Page	Case	Motion	Data	Measurement	Run No.	File Name
1	1	static	Case 1 (Data and Test Conditions)	loads	L02211-L02231	data-cs3-1-2-3
	2	static	Case 2 (Data and Test Conditions)	pressure	L11000-L11014	
	3	harmonic	Case 3 (Test Conditions)	loads/pressure		
2-6			Case 3 (Data Run No. L02158)	loads	L02158	data-case3 / c3-2
7-11			Case 3 (Data Run No. L02157)	loads	L02157	
12-16			Case 3 (Data Run No. L02156)	loads	L02156	
17-21			Case 3 (Data Run No. L02155)	loads	L02155	
22-26			Case 3 (Data Run No. L02178)	loads	L02178	
27-31			Case 3 (Data Run No. L02177)	loads	L02177	
32-36			Case 3 (Data Run No. L02176)	loads	L02176	
37-41			Case 3 (Data Run No. L02175)	loads	L02175	
42-46			Case 3 (Data Run No. L11273)	pressure	L11273	data-case3 / c3-3
47-51			Case 3 (Data Run No. L11274)	pressure	L11274	
52-56			Case 3 (Data Run No. L11275)	pressure	L11275	
57-61			Case 3 (Data Run No. L11276)	pressure	L11276	
62	4	ramp	Case 4 (Test Conditions)	loads		data-case4 / c4-1
63-67			Case 4 (Data Run No. DW03411)	loads	DW03411	data-case4 / c4-2
68-72			Case 4 (Data Run No. DW03412)	loads	DW03412	
73-77			Case 4 (Data Run No. DW03413)	loads	DW03413	
78-82			Case 4 (Data Run No. DW03414)	loads	DW03414	
83-87			Case 4 (Data Run No. DW03415)	loads	DW03415	
88-92			Case 4 (Data Run No. DW03416)	loads	DW03416	
93-97			Case 4 (Data Run No. DW03417)	loads	DW03417	
98-102			Case 4 (Data Run No. DW03418)	loads	DW03418	
103-107			Case 4 (Data Run No. DW03419)	loads	DW03419	
108-112			Case 4 (Data Run No. DW03420)	loads	DW03420	
113-117			Case 4 (Data Run No. DW03421)	loads	DW03421	
118-122			Case 4 (Data Run No. DW03422)	loads	DW03422	
123-127			Case 4 (Data Run No. DW03423)	loads	DW03423	
128-132			Case 4 (Data Run No. DW03424)	loads	DW03424	
133-137			Case 4 (Data Run No. DW03425)	loads	DW03425	
138-142			Case 4 (Data Run No. DW03426)	loads	DW03426	
143-146	5	static	Case 5 (Data and Test Conditions)	loads	SW01000-01316	data-case5 / c5-1
147	6	harmonic	Case 6 (Test Conditions)	loads/pressure		data-case6 / c6-1
148-152			Case 6 (Data Run No. L00371)	loads	L00371	data-case6 / c6-2
153-157			Case 6 (Data Run No. L00354)	loads	L00354	
158-162			Case 6 (Data Run No. L10290)	pressure	L10290	data-case6 / c6-3
163-167			Case 6 (Data Run No. L00384)	loads	L00384	data-case6 / c6-4
168-172			Case 6 (Data Run No. L00359)	loads	L00359	
173-177			Case 6 (Data Run No. L10293)	pressure	L10293	data-case6 / c6-5
178	7	ramp	Case 7 (Test Conditions)	loads		data-case7 / c7-1
179-183			Case 7 (Data Run No. DW03000)	loads	DW03000	data-case7 / c7-2
184-188			Case 7 (Data Run No. DW03001)	loads	DW03001	
189-193			Case 7 (Data Run No. DW03002)	loads	DW03002	
194-198			Case 7 (Data Run No. DW03003)	loads	DW03003	
199-203			Case 7 (Data Run No. DW03004)	loads	DW03004	
204-208			Case 7 (Data Run No. DW03005)	loads	DW03005	
209-213			Case 7 (Data Run No. DW03006)	loads	DW03006	
214-218			Case 7 (Data Run No. DW03007)	loads	DW03007	
219-223			Case 7 (Data Run No. DW03036)	loads	DW03036	
224-228			Case 7 (Data Run No. DW03037)	loads	DW03037	

Table 3(cont.) Electronic data file index

Page	Case	Motion	Data	Measurement	Run No.	File Name
229-233	7	ramp	Case 7 (Data Run No. DW03038)	loads	DW03038	data-case7 / c7-2
234-238			Case 7 (Data Run No. DW03039)	loads	DW03039	
239-243			Case 7 (Data Run No. DW03040)	loads	DW03040	
244-248			Case 7 (Data Run No. DW03041)	loads	DW03041	
249-253			Case 7 (Data Run No. DW03042)	loads	DW03042	
254-258			Case 7 (Data Run No. DW03043)	loads	DW03043	
259-263			Case 7 (Data Run No. DW03044)	loads	DW03044	
264-268			Case 7 (Data Run No. DW03050)	loads	DW03050	
269-273			Case 7 (Data Run No. DW03053)	loads	DW03053	
274-278			Case 7 (Data Run No. DW03055)	loads	DW03055	
279-281	8	static	Case 8 (Data and Test Conditions)		SW01142-01262	data-case8 / c8-1
282	9	harmonic	Case 9 (Test Conditions)	loads/pressure		data-case9 / c9-1
283-287			Case 9 (Data Run No. L01360)	loads	L01360	data-case9 / c9-2
288-292			Case 9 (Data Run No. L10379)	pressure	L10379	data-case9 / c9-3
293-297			Case 9 (Data Run No. L01111)	loads	L01111	data-case9 / c9-4
298-302			Case 9 (Data Run No. L10447)	pressure	L10447	data-case9 / c9-5
303	10	forced free-to-roll	Case 10 (Test Conditions)	pressure		data-case10 / c10-1
304-309			Case 10 (Data Run No. TW00001 / TT00001)	pressure	TW00001 / TT00001	data-case10 / c10-2
310-315			Case 10 (Data Run No. TW00009 / TT00009)	pressure	TW00009 / TT00009	data-case10 / c10-2
316-321			Case 10 (Data Run No. TW00032 / TT00040)	pressure	TW00032 / TT00040	data-case10 / c10-2
322-327			Case 10 (Data Run No. TW00046 / TT00034)	pressure	TW00046 / TT00034	data-case10 / c10-2

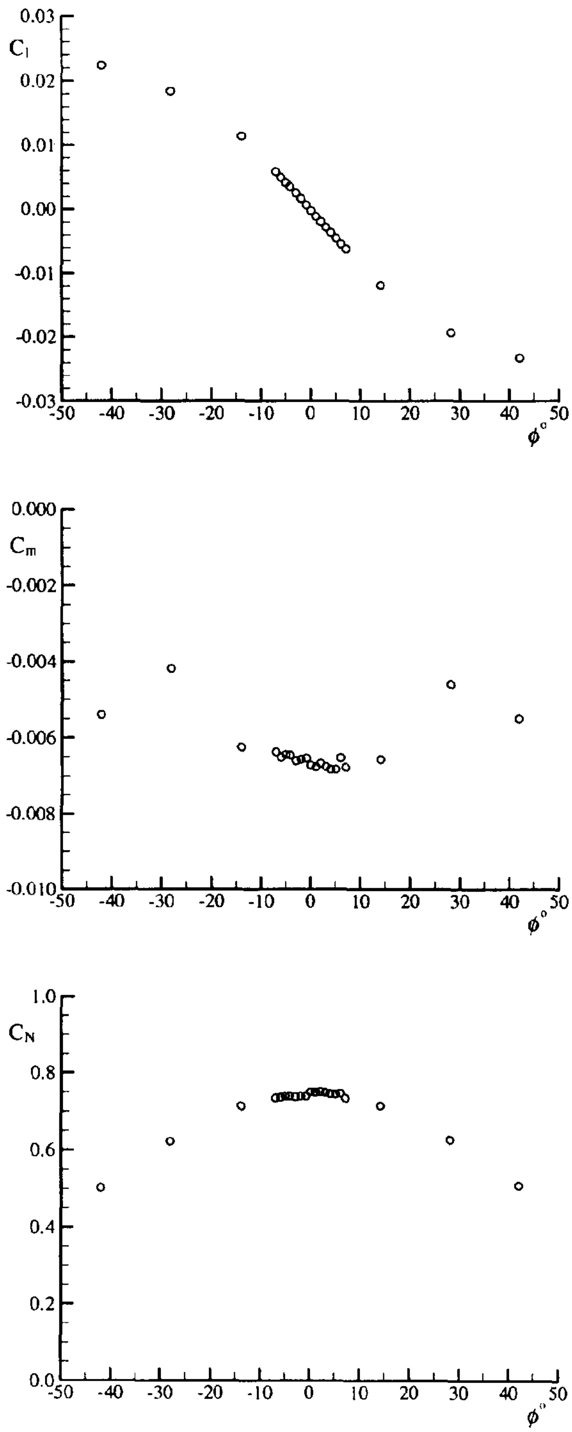


Fig.Case 1 Run No. L02211 - L02231

$\sigma = 15^o$ $P_o = 13.355$ psi
$\phi = -42^o \sim +42^o$
$M = 0.29$

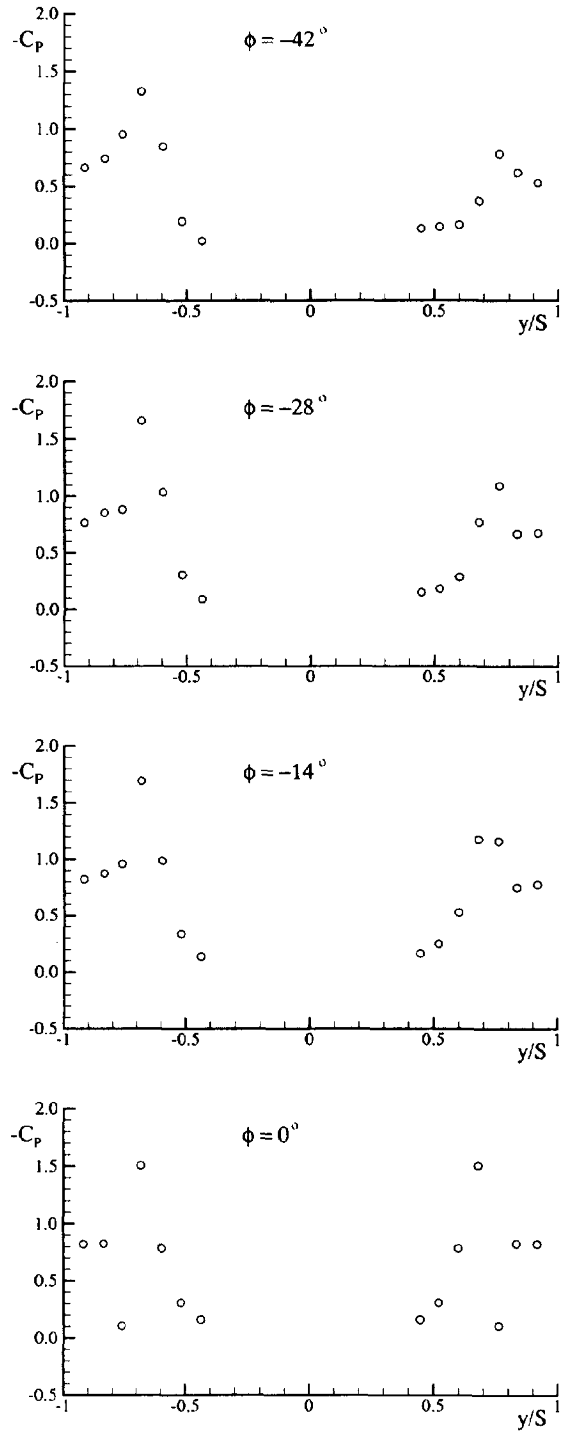


Fig.Case 2-1 Run No. 11000 - L11014

$\sigma = 15^o$ $P_o = 13.427$ psi
$T_o = 22.2^o$ $q = 0.806$ psi
$M = 0.29$ $P_{atm} = 14.254$ psi

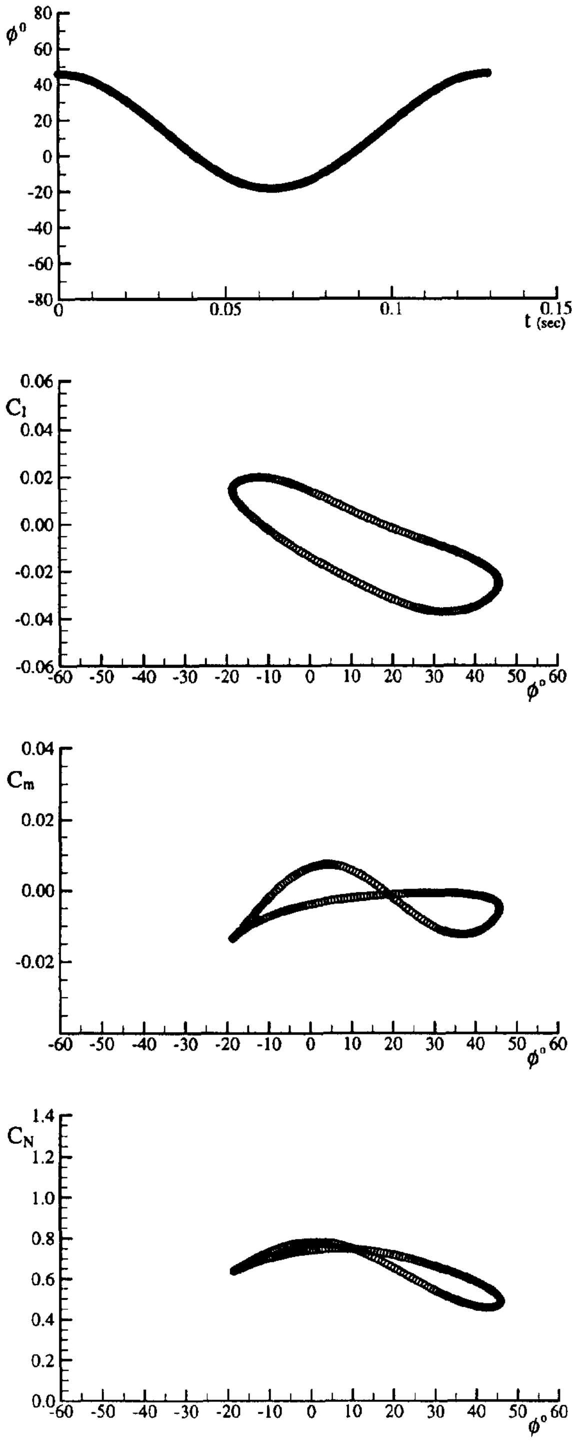


Fig.Case 3-7 Run No. L02176

$\sigma = 15°$ f = 7.7
$\phi_o = 13.645°$ P_o = 13.427 psi
$\Delta\phi = 32.176°$ M = 0.29

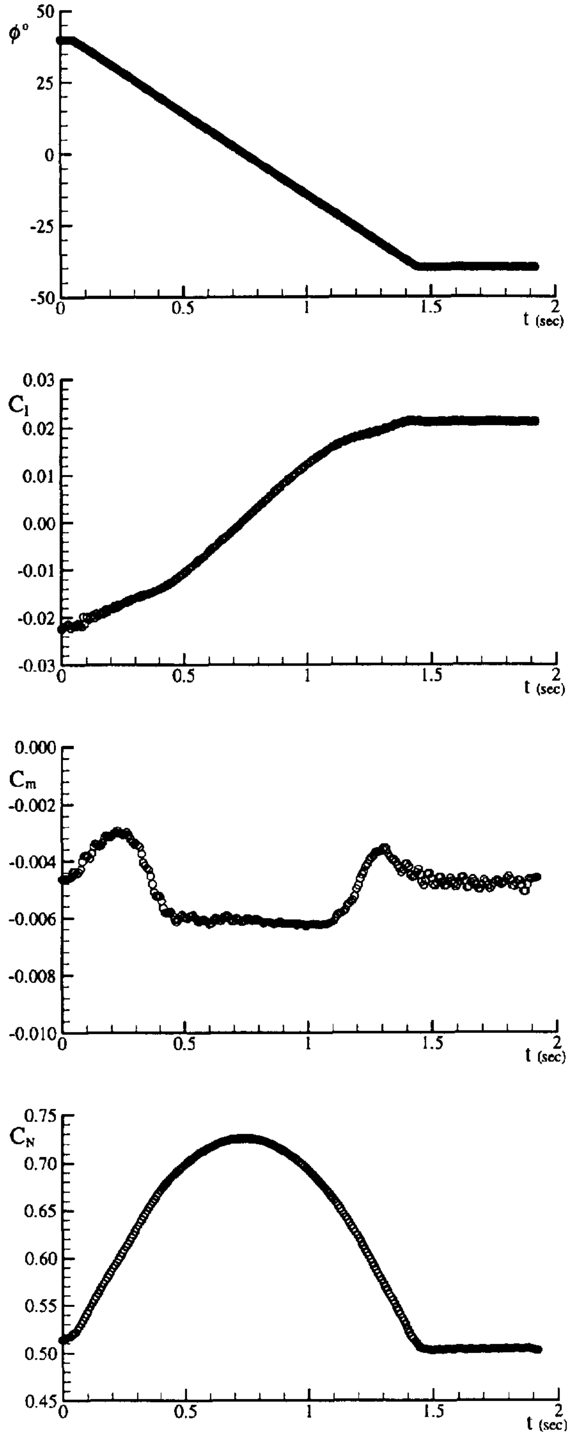


Fig.Case 4-8 Run No. DW03418

$\sigma = 15°$ $\dot{\Phi}$ = 1 rad/sec
$\phi_o = 40°$ P_o = 13.378 psi
$\phi_l = -40°$ M = 0.29

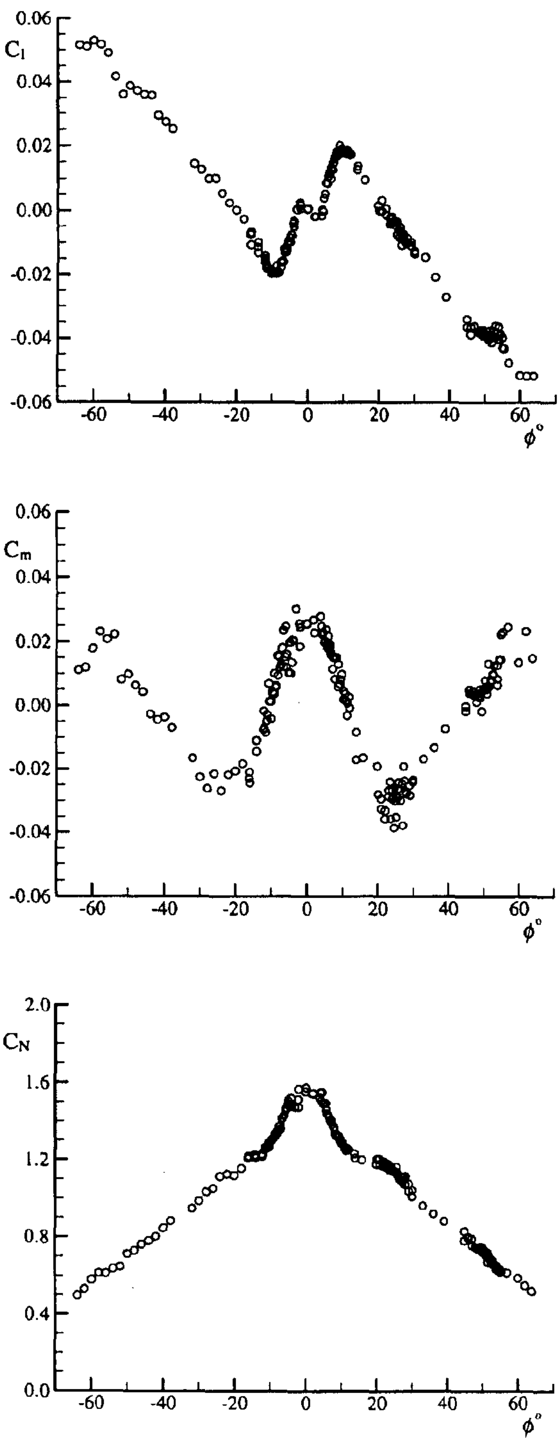


Fig.Case 5 Run No. SW01000 - 01141
SW01290 - 01420

$\sigma = 30^\circ$ $P_o = 13.355$ psi
$\phi = -64^\circ \sim +64^\circ$ $M = 0.29 \sim 0.31$

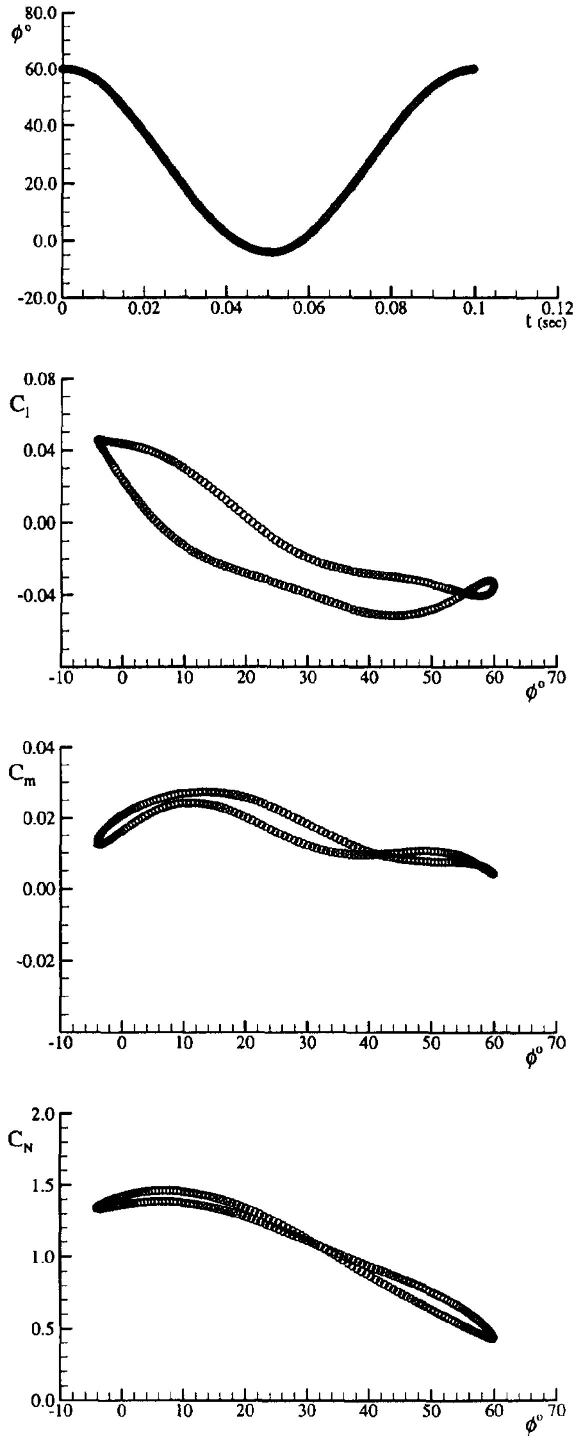


Fig.Case 6-4 Run No. L00384

$\sigma = 30^\circ$ $f = 10$
$\phi_o = 27.359^\circ$ $P_o = 14.602$ psi
$\Delta\phi = 31.502^\circ$ $M = 0.264$

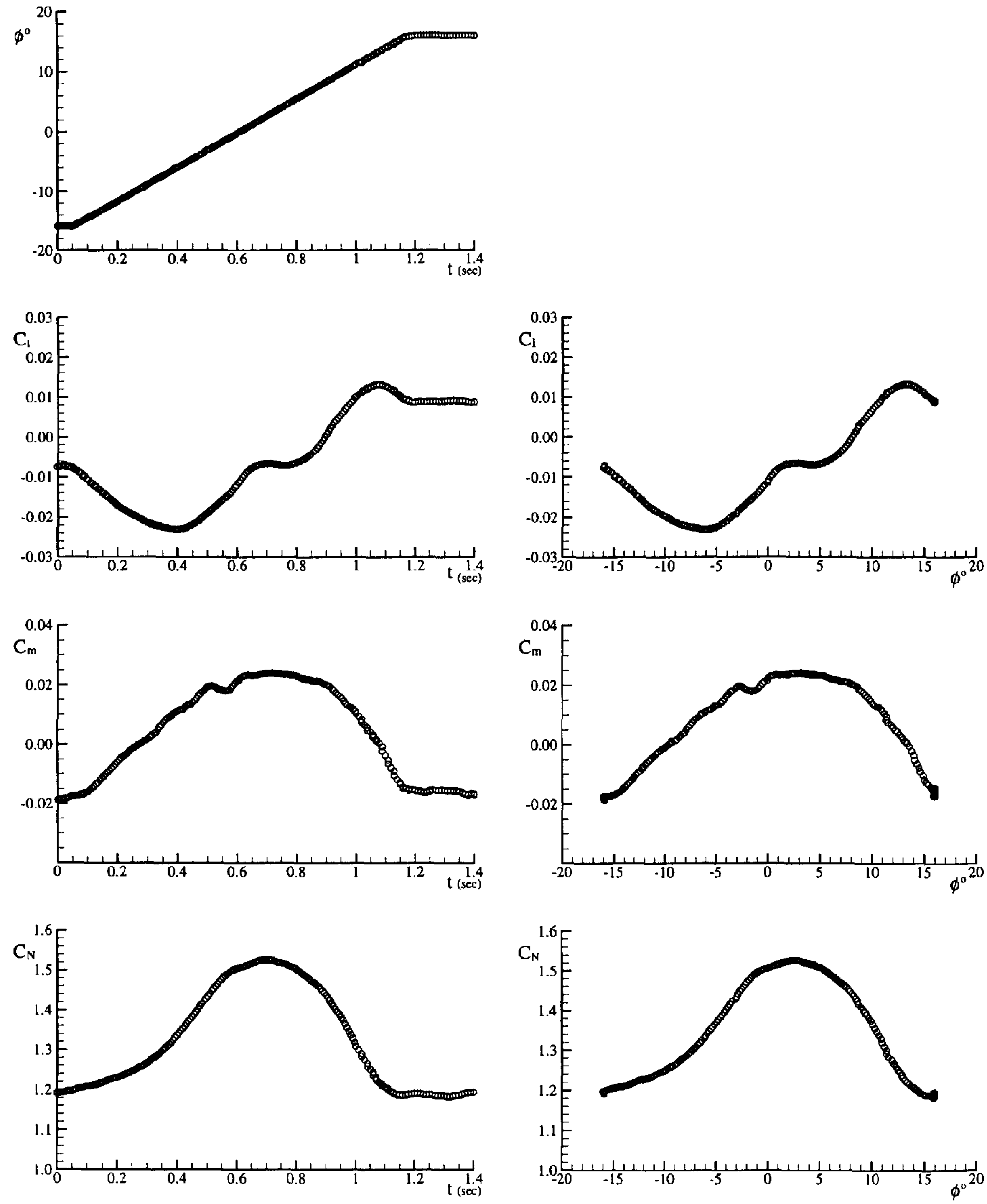


Fig.Case 7-1 Run No. DW03000

$\sigma = 30^o$ $\dot{\Phi} = 0.5$ rad/sec

$\phi_o = -16^o$ $P_o = 13.574$ psi

$\phi_1 = 16^o$ $M = 0.30$

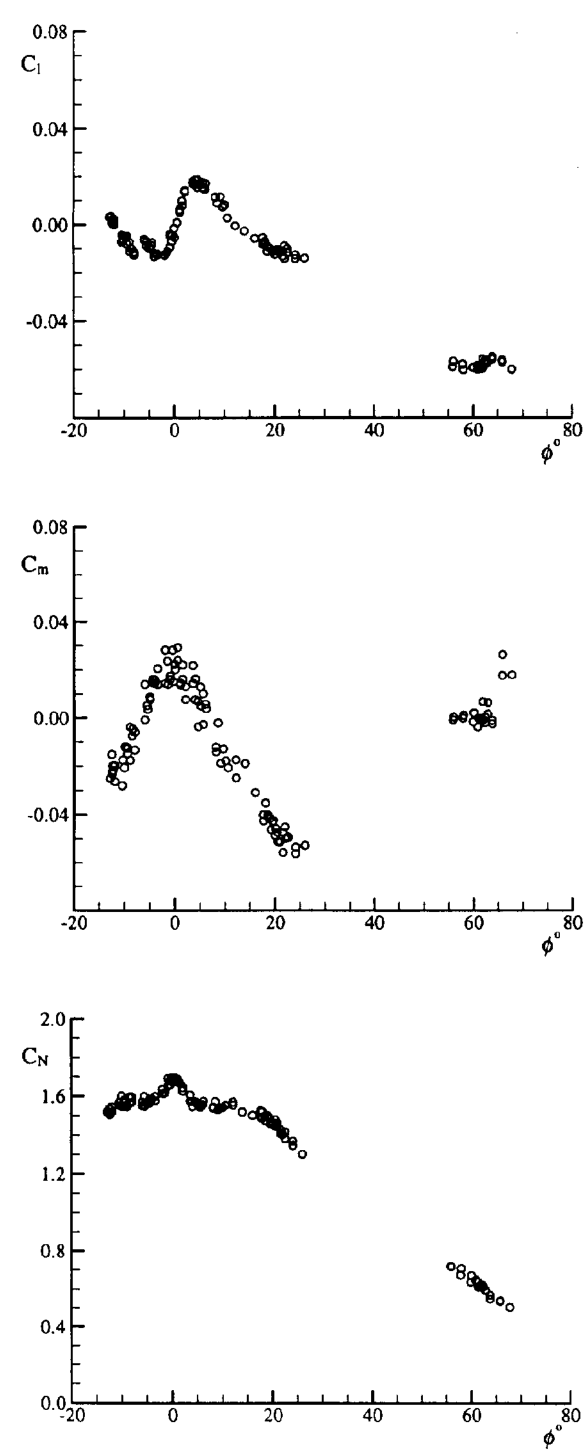


Fig.Case 8 Run No. SW01142 - 01262

$\sigma = 35^\circ$ $M = 0.30$

$\phi = -12^\circ \sim +68^\circ$

$P_o = 13.342 \sim 13.432$ psi

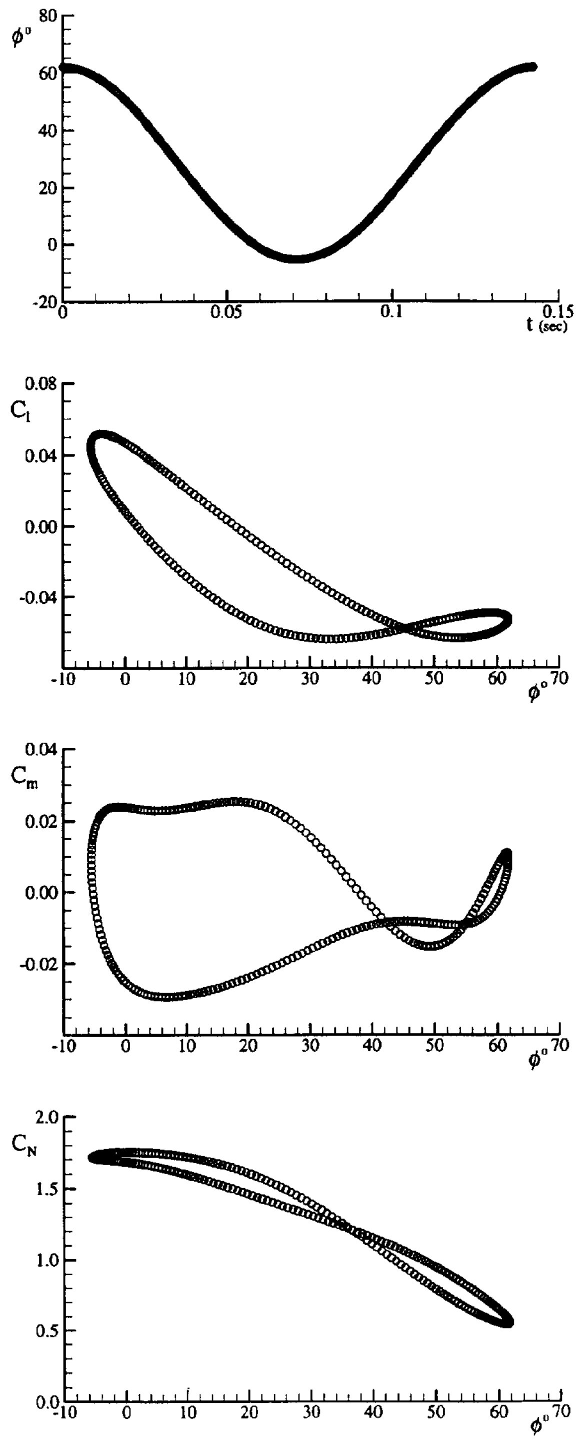


Fig.Case 9-3 Run No. L01111

$\sigma = 35^\circ$ $f = 7$

$\phi_o = 28.176^\circ$ $P_o = 14.672$ psi

$\Delta\phi = 33.646^\circ$ $M = 0.264$

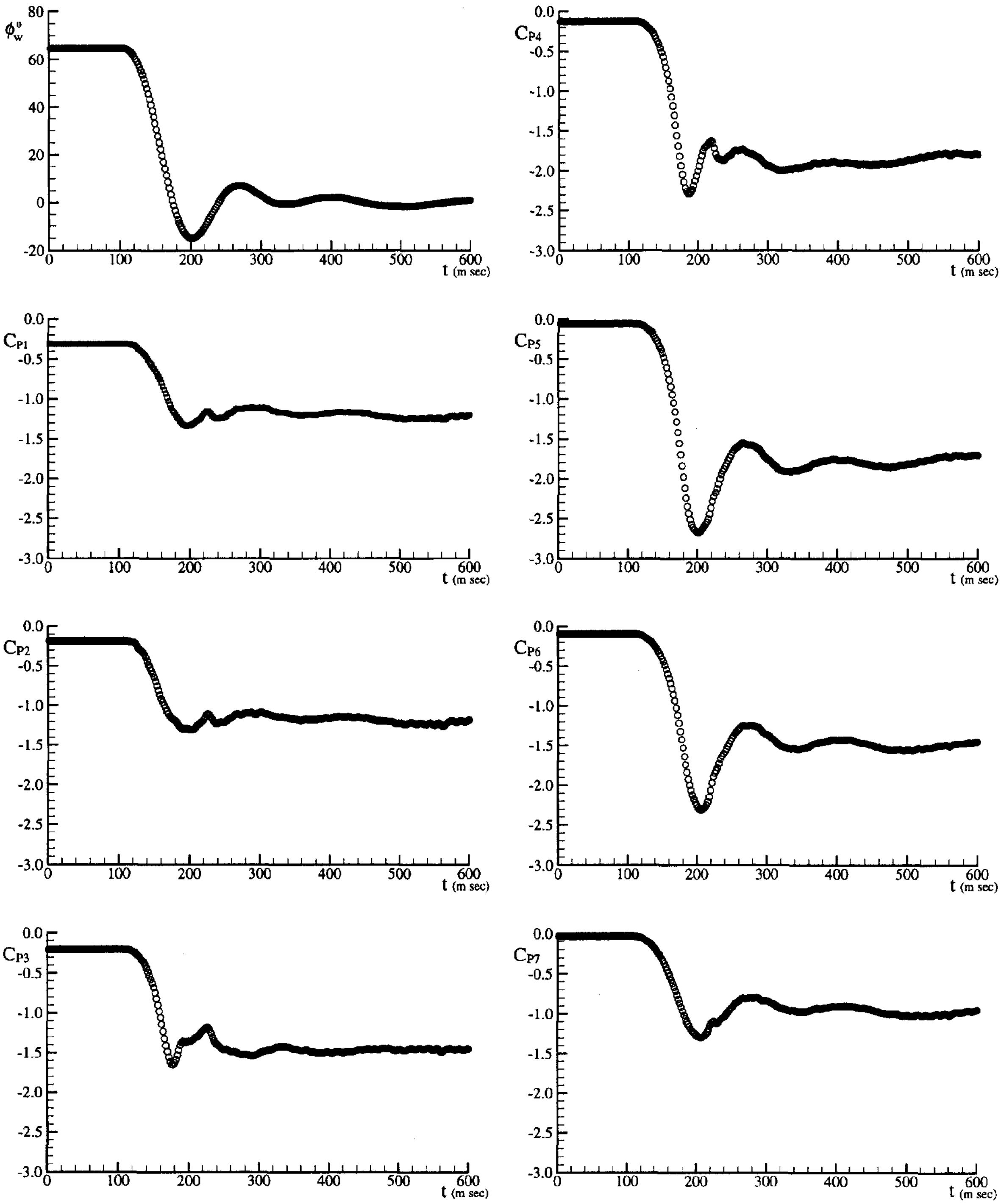


Fig.Case 10-1 Run No. TW00001 / TT00001

$\sigma = 30°$ $M = 0.27$ (TW00001)

$\phi_o = 64.000°$ $M = 0.00$ (TT00001)

$P_o = 13.572$ psi

Table 4 Examples of lay-out of data files

Case 1 (Data and Test Conditions)

Run No.	σ°	φ°	C_l	C_m	C_N	C_Y	C_n	T_0(°C)	P_0(psi)	M	V_0(ft/sec)	q (psi)	atm (psi)
L02211	15	-41.995	0.0224	-0.0054	0.502	0.01275	-0.00007	20.5	13.355	0.29	329.0	0.799	14.181
L02212	15	-28.044	0.0184	-0.0042	0.623	0.01009	-0.00025	20.5	13.355	0.29	329.0	0.799	14.181
L02213	15	-13.912	0.0113	-0.0062	0.713	0.00491	0.00003	20.5	13.355	0.29	329.0	0.799	14.181

Case 2 (Data and Test Conditions)

Run No.	σ°	φ°	Cp_1	Cp_2	Cp_3	Cp_4	Cp_5	Cp_6	Cp_7	T_0°C	P_0(psi)	M	V_0(ft/sec)	q (psi)	atm (psi)
L11000	15	-41.881	-0.6722	-0.7502	-0.9437	-1.3365	-0.8449	-0.1978	-0.0265	22.2	13.427	0.29	331.0	0.806	14.254
L11001	15	-27.975	-0.7451	-0.8353	-0.9074	-1.6457	-1.0368	-0.3017	-0.0835	22.2	13.427	0.29	331.0	0.806	14.254
L11002	15	-13.909	-0.8262	-0.8823	-0.9569	-1.6905	-0.9928	-0.3431	-0.1414	22.2	13.427	0.29	331.0	0.806	14.254

Case 3 (Data Run No. L02158)

σ°	$φ_0$°	Δφ°	f	P_0(psi)	M	V_0(ft/sec)	q (psi)
15	-0.046	18.752	7.7	13.398	0.29	329	0.856

No.	Time (sec)	φ(t)°	C_l	C_m	C_N	C_y	C_n
1	0.000000	18.704	-0.0163	-0.0064	0.654	-0.02070	0.00177
2	0.000507	18.690	-0.0165	-0.0064	0.654	-0.02088	0.00176
3	0.001015	18.666	-0.0167	-0.0064	0.654	-0.02104	0.00175

Case 3 (DataRun No. L11273)

σ°	$φ_0$°	Δφ°	f	T_0(°C)	P_0(psi)	M	V_0(ft/sec)	q (psi)	atm (psi)
15	-0.397	39.759	7.7	24.9	13.456	0.29	333.05	0.813	14.297

No.	Time (sec)	φ(t)°	Cp_1	Cp_2	Cp_3	Cp_4	Cp_5	Cp_6	Cp_7
1	0.000000	39.326	-0.5731	-0.6263	-0.8655	-0.4511	-0.1785	-0.1421	-0.1335
2	0.000507	39.272	-0.5755	-0.6297	-0.8688	-0.4543	-0.1804	-0.1437	-0.1349
3	0.001015	39.193	-0.5780	-0.6331	-0.8725	-0.4579	-0.1825	-0.1454	-0.1363

Case 4 (Data Run No. DW03413)

σ°	$φ_0$°	$φ_1$°	$\dot{φ}$(rad/sec)	P_0(psi)	M	V_0(ft/sec)	q (psi)
15	20	9	0.5	13.378	0.30	336.4	0.856

No.	Time (sec)	φ(t)°	C_l	C_m	C_N	C_y	C_n
1	0.00000	19.978	-0.0150	-0.0057	0.671	-0.00668	0.00033
2	0.00357	19.978	-0.0150	-0.0057	0.671	-0.00574	0.00061
3	0.00714	19.978	-0.0150	-0.0057	0.671	-0.00798	0.00048

Case 5 (Data and Test Conditions)

Run No.	σ°	φ°	C_l	C_m	C_N	C_Y	C_n	T_0(°C)	P_0(psi)	M	V_0(ft/sec)	q (psi)	atm (psi)
SW01000	30	-15.978	-0.0107	-0.0210	1.207	-0.03297	0.00314	19.3	13.401	0.30	330.5	0.825	14.181
SW01001	30	-13.981	-0.0132	-0.0144	1.215	-0.11537	-0.00040	19.0	13.407	0.30	330.1	0.824	14.426
SW01002	30	-11.998	-0.0159	-0.0017	1.227	-0.05010	0.00196	18.9	13.400	0.30	331.5	0.830	14.263

Case 10 (Data Run No. TW00001 / TT00001)

Run No.	σ°	$φ_0$°	T_0(°C)	M	P_0(psi)	V_0(ft/sec)	q (psi)	atm (psi)
TW00001	30	64.000	21.27	0.27	13.572	300.0	1.421	14.268
TT00001	30	64.000	25.65	0.00	13.572	0.0	0.000	13.543

Time (ms)	$φ_w$°	$φ_t$°	Cp_1	Cp_2	Cp_3	Cp_4	Cp_5	Cp_6	Cp_7
2	64.512	64.152	-0.3090	-0.1860	-0.2060	-0.1270	-0.0610	-0.0990	-0.0350
4	64.512	64.116	-0.3080	-0.1860	-0.2070	-0.1240	-0.0590	-0.0990	-0.0370
6	64.512	64.116	-0.3090	-0.1870	-0.2060	-0.1260	-0.0610	-0.0990	-0.0360